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OPERATIONAL NOTE

SAMPLERS FOR EVALUATION AND QUANTIFICATION OF ULTRA-LOW VOLUME SPACE SPRAYS[1]

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ABSTRACT. A field study was conducted to explore the suitability of 5 pesticide deposition samplers for airborne spray and ground deposits from ultra-low-volume (ULV) space sprays. Samplers included horizontally stretched stationary cotton ribbons at 2 heights, rotating ribbon, rotating Teflon slides, and filter paper. Slides were also used for droplet-size analysis. A set of 7 samplers of each type was placed at 1, 7, 15, 25, 40, 65, and 90 m from the spray line along the spray swath. Water and BVA13 oil with fluorescent dyes as tracers were sprayed with the use of a truck-mounted ULV sprayer at dusk and dawn. Results suggest that the horizontal and rotating cotton ribbons are best for quantification of airborne spray and filter paper is best for ground deposition collection. The rotating slide samplers only detected the BVA13 oil-based sprays.

KEY WORDS Ultra-low-volume (ULV) sprays, sprayer evaluation, spray flux, samplers, deposition

Ultra-low-volume (ULV) applications are widely used space sprays for the control of flying insects. The fundamental objective of a spray delivery system (sprayer) is to transport the pesticide in an efficacious form to the location where it is required. A sprayer's primary functions are formation of droplets and their delivery to the target. Evaluations of ULV sprayers in the past have relied either on bioassays (George et al. 1968, Brown et al. 2002, Lothrop et al. 2007a) or on droplet-size measurement (Johnson 1974; Hoffmann et al. 2007a, 2007b). Lothrop et al. (2007b) used filter paper to measure ground deposit of 2 active ingredients (AIs; pyrethrins and piperonyl butoxide) from aerial sprays and analyzed the samples with high-performance liquid chromatography, but could detect only 1 AI past 60 m from the spray line. Field bioassays are useful for pesticide efficacy evaluations (Townzen et al. 1989), but insect mortality cannot always be attributed to better sprayer performance and vice versa. Droplet size characterization is limited to laboratories and helps evaluate droplet formation function of the sprayers only. Effective techniques for field measurement of droplets still do not exist.

Any sprayer evaluation should assess the achievement level for functions of a sprayer and its sensitivity to operating parameters. To date, there have been no reports on the effect of various application parameters, such as operating pressure, travel speed, application rates, spray discharge velocity, and air-flow rates on the dispersion of a ULV spray because of unavailability of proper evaluation techniques. Spray application systems are promoted merely on expectations, some of which have been proved baseless (Salyani and Farooq 2003). New challenges resulting from ever-growing restrictions on pesticide use for public health demand comprehensive and efficient evaluation of sprayers for which suitable methodologies are needed, and this study is a step toward establishing the same. Thornhill (1982) has described methods to assess sprayer durability only. The objectives of this study were to assess suitability of 5 spray sampling techniques for deposit and airborne components of ULV space sprays.

The study was conducted in a 110 × 130–m mowed, grassy (15 cm tall) area along a runway at Whitehouse Naval Outlying Field near Jacksonville, FL. Four artificial targets were used for airborne spray collection and 1 for ground deposit. A set of 7 samplers of each type was placed at 1, 7, 15, 25, 40, 65, and 90 m from the spray line. Of the 2 tank mixtures, 1 contained 3,000 ppm of Caracid Brilliant Flavine FFS fluorescent dye (Carolina Color and Chemical Co., Charlotte, NC) and 0.05% nonionic surfactant (R-11, Wilbur-Ellis, Devine, TX) in water. The 2nd had 1,000 ppm of Uvitex OB dye (Ciba Corporation, Newport, DE) in BVA13 oil. The water-based mixture also had a triple-pass application to test the need for more than 1 pass. Three replicated treatments made a total of 9 applications. The water-based applications were

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Fig. 1. Ultra-low-volume space spray samplers.

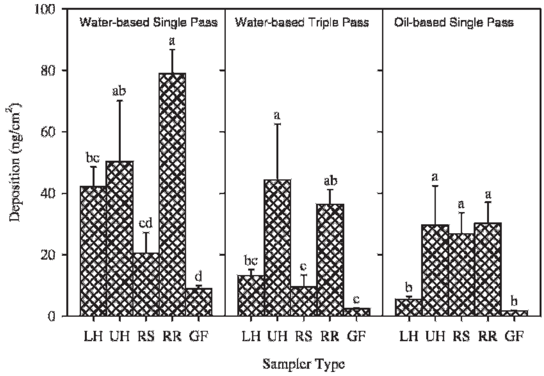

Fig. 2. Comparison of dye collection by samplers in each application (LH, lower horizontal ribbon; UH, upper horizontal ribbon; RS, rotating slide; RR, rotating ribbon; GF, ground filter; for each treatment; means with same letters are not significantly different [t-test, $\alpha < 0.05$]).

alternated, and the oil-based applications were made at the end. Five applications were made from 1900 h to 2300 h on April 21, 2008, and 4 were made between 0700 h and 0900 h on April 22, 2008. Sunrise and sunset on these dates were at 0650 and 2000 h, respectively.

A London Fog 18-20 (London Fog, Long Lake, MN), truck-mounted ULV sprayer was used in this study. It is powered by a 13.2-kw gasoline engine and is equipped with an air-shear nozzle. The rotary, positive-displacement blower produces an air flow of 10.1 m^3/min at the nozzle. The sprayer discharged the spray horizontally and perpendicular to the travel direction at 2 m height. It was operated at 0.65 liters/min and 16 km/h to produce an application rate of 0.265 liters/ha.

All the applications used the same area of the field and new samplers were placed before each application. Figure 1 shows 4 of the 5 samplers used for this study. Two 1-m-long, 2.5-cm-wide biodegradable cotton ribbons (Lab Safety Supply Inc., Janesville, WI) stretched horizontally between 2 holders at 0.9- and 1.8-m heights to collect airborne spray, and were called lower horizontal (LH) and upper horizontal (UH). The same ribbon was stretched to collect ground deposit, but was discontinued due to inaccurate representation of ground surface. A rotating ribbon sampler (RR) was built on the drive of aerosol droplet sampler (Model 212, John W. Hock Company, Gainesville, FL) that used a 45-cm-long cotton ribbon attached to a U-shaped bracket with binder clips on both sides at 1.3-m height above ground. A 12.5-cm-diameter filter paper (Grade E Microfiber Filter, The Lab Depot, Dawsonville, GA) was employed to measure ground deposit (GF). Two Teflon-coated microscope slides mounted on aerosol droplet sampler, at 1.3-m height and rotating at 450 rpm, were also used for collection of airborne spray.

New filters, ribbons, and slides were put in place before each application. Ten minutes post-treatment, all the samples were collected simultaneously. The ribbons were cut near the mount, discarding ends to avoid contamination, and stored separately in prelabeled plastic bags. The filter papers were removed from the cardboard with a pair of tweezers and placed in bags. Of each pair of slides, 1 was stored in a bag for washing and the other was preserved for droplet-size determination. All the samples were stored in an ice chest for transport to the laboratory and in a refrigerator for subsequent analysis.

Each water-based and oil-based sample was washed in a bag with 50 ml (V_w) distilled water and 25 ml (V_w) denatured ethanol, respectively. The samples were all submersed in the bag, soaked for 5 min, and shaken for 4 min by a platform shaker. The wash solution was poured into 2 10-ml cuvettes and read with a fluorometer (Model 700, Turner Design Inc., Sunnyvale, CA). The raw fluorometer readings were converted to dye concentration (C_{ws}) with calibrations obtained from a standard solution. The surface area (A_s) for each sample was calculated by using the dimensions for the ribbons, filters, and slides. The dye deposition on samplers was determined with the following formula:

$$\mathrm{Dep} = \frac{1{,}000 C_{ws} V_w}{A_s},$$

where Dep = deposition of dye on sampler surface (ng/cm^2), C_{ws} = concentration of dye in wash solution (ppm or µg/ml), V_w = wash volume (ml), and A_s = surface area of the samplers (cm^2).

Deposition is defined as the spray mass deposited per unit surface area. The airborne spray samplers captured material passing through

Table 1. Weather conditions during applications.

Treatment	Replication	Wind speed (km/h ± SD)	Wind direction range (degrees)	Temperature (°C)	RH (%)
Water-based single pass	1	13.3 ± 2.7	323–338	25.89	75
	2	16.9 ± 1.5	291–299	25.76	75
	3	11.7 ± 1.5	301–315	25.64	78
Water-based triple pass	1	17.7 ± 2.6	291–319	26.00	75
	2	11.2 ± 2.5	290–310	26.13	78
	3	6.7 ± 1.0	270–280	13.09	93
Oil-based single pass	1	6.4 ± 0.8	280–290	13.10	93
	2	6.2 ± 0.6	280–290	13.00	93
	3	7.1 ± 1.5	285–340	15.51	73

a vertical plane oriented to the samplers, a measure of spray flux. For this study, the mass of dye/cm^2 was reported as deposition. For applications using AIs, the dye deposition can be changed to AI deposition with dye to AI ratio in the spray mixture. The deposition data for triple-pass application was reduced by a factor of 3 to match with volume application rate of the single-pass application. Statistical analysis was performed with the JMP software version 5 (JMP, Cary, NC). The means were compared with the use of the *t*-test at 95% level of confidence.

Wind speed, wind direction, and temperature were measured with a 3-D sonic anemometer (Model 81000, R.M. Young Company, Traverse City, MI) at 3-m height and 25 m from the field halfway through the swath. Relative humidity was obtained from the Whitehouse airport weather station. The wind direction (Table 1) was from the northwest on Day 1 (1st 5 tests) and more westerly on Day 2 (last 4 tests). The sampling layout was adjusted between days to orient sample lines perpendicular to the winds.

Averaged over samplers and distances, and adjusted for spray volumes, the water-based single-pass (WBSP), water-based triple-pass (WBTP), and oil-based single-pass (OBSP) applications resulted in deposits of 40.1, 21.2, and 18.7 ng/cm^2, respectively. The rotating ribbon (RR) sampler collected the most amount of dye but nonsignificantly different from the UH, whereas deposits on the LH were the same as on the rotating slide (RS). Averaged over distances, the RR and UH had similar deposit for WBSP and WBTP applications (Fig. 2). For the OBSP application, the RR, the UH, and the RS had similar deposition. Averaged over treatments, the UH had the highest deposition of the samplers nearest to the spray line, whereas the RR samplers had highest deposition at all other distances (Table 2). For water-based applications, Teflon-coated slides had too few measurable droplets to analyze. The volume medium diameter ($D_{v0.5}$) of droplets for oil-based applications ranged from 13.5 to 15.3 μm, and the collected droplets did not show considerable change with increasing distance from the spray line. The results in this study envision the replacement of cumbersome bioassay methods by flux measurements to evaluate spray delivery systems. Based on these results, either stationary or rotating ribbon sampler is recommended for quantification of spray flux in ULV space sprays.

During spray dispersion, smaller eddies enlarge the spray cloud and decrease its density as the larger eddies, i.e., wind velocity, move it away from the sprayer (Bache and Johnston 1992, Farooq 2002). This causes decreased deposits on aerial samplers (spray flux) as the distance from the sprayer increases (Table 2). This trend agrees with field bioassay studies reported by Taylor and Schoof (1968) when mortality of 3 species (*Aedes aegypti* (L.), *Anopheles albimanus* Wiedemann, *Culex quinquefacsciatus* Say) subjected to 2 insecticides decreased with distance from 45 to 90 m from sprayer. George et al. (1968), using naled and malathion to control *A. aegypti* and *Culex pipiens* (L.), respectively, showed reduction in mosquito

Table 2. Mean deposition for all treatments on various samplers at different distances from spray line.[1]

Sampler	Deposition (ng/cm^2) at distance (m) away from spray line						
	1	7	15	25	40	65	90
Horizontal ribbon at 0.9 m	34.7 A bc	15.5 A b	21.4 A b	22.8 A ab	12.8 A b	20.1 A ab	14.1 A ab
Horizontal ribbon at 1.8 m	200.4 A a	14.3 B b	16.7 B b	16.2 B b	15.3 B b	14.4 B ab	12.5 B ab
Rotating ribbon	85.0 A b	71.0 A a	58.5 AB a	36.7 BC a	37.9 BC a	25.8 C a	24.5 C a
Rotating slide	58.3 A bc	24.9 B b	16.8 B b	12.8 B b	7.0 B b	7.0 B ab	5.7 B b
Filter on ground	4.3 A c	5.5 A b	4.7 A b	4.1 A b	2.9 A b	4.6 A b	4.2 A b

[1] Means followed by the same uppercase letter in a row or lowercase letter in a column were not significantly different (*t*-test, $\alpha < 0.05$).

mortality with increasing distance from the sprayer.

Higher winds over vegetation generate rolling vortices that enhance mixing of the spray, move it faster through the space, and keep it close to the ground (D. Miller, personal communication). Increase in collection efficiency of airborne samplers with increased wind speed (Miller 1993), tied to rolling vortices, contributed to higher deposition from water-based than from oil-based sprays (Table 2). These results make one theorize that higher winds might help keep the spray near to the ground and enhance the efficacy of space spray. However, further comprehensive investigation to understand this spray dispersion phenomenon is recommended; the findings might pave the way for daytime applications or increase the window of operation for ULV space sprays.

Oversampling of the air volume by rotating samplers makes it a better collector for low-concentration areas such as the end of the swath. However, this oversampling must be corrected with the use of the sampler's collection efficiencies, which still need to be assessed. The airborne samplers recommended after this study measure the amount of spray passing through a vertical plane oriented perpendicular to the wind direction in the form of deposition, a metric of suitability for a sprayer that can be transformed to a metric of a spray application by relating spray deposition (flux) to insect mortality.

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